

# $J/\Psi$ production in $\pi N$ collisions <sup>\*</sup>

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## Abstract

We calculate the total cross section for  $\pi N \rightarrow J/\Psi N$  based on  $\rho$ -meson exchange. On the basis of this calculation we predict a maximal reaction rate arising from the OZI-violating  $J/\Psi \leftrightarrow \rho\pi$  vertex in tree-level. Our estimate for the maximum reaction rate is still one order of magnitude smaller than the existing predictions which were based on the other OZI-violating mechanisms.

The production of  $J/\Psi$ -mesons in hadronic reactions is an extremely sensitive tool for studying the Okubo-Zweig-Iizuka (OZI) rule [1]. The OZI rule is based on the assumption that the contribution from processes involving the production of quark-antiquark ( $q\bar{q}$ ) pairs not available in the initial state ideally equals zero. Thus, a violation of the OZI rule might be regarded as evidence for a hidden  $q\bar{q}$  component in the initial hadrons [2]. In case of the  $J/\Psi$  production in  $\pi N$  collisions the OZI violation directly leads to the percentage of the  $c\bar{c}$  component in the nucleon, or hidden charm [3].

There are several studies of the  $J/\Psi$  production based on the OZI-violating mechanisms. For example, within the duality violating model Bolzan et al. [4] predicted a  $\pi^- p \rightarrow J/\Psi n$  total cross section of 1.0 to 2.5 nb in the threshold enhancement region. A similar result was obtained by Kodaira and Sasaki [5] using a generalized Veneziano model, which assumed the production of  $J/\Psi$ -meson was through mixing with the spin one daughters of the  $\omega$  recurrences. Berger and Sorensen [6] predicted an enhanced rate for the  $\pi^- p \rightarrow J/\Psi n$  reaction at pion momenta around 10-12 GeV, when the  $J/\Psi$ -mesons fit into a  $c\bar{c}$  scheme. The prediction was according to the analogy of the study

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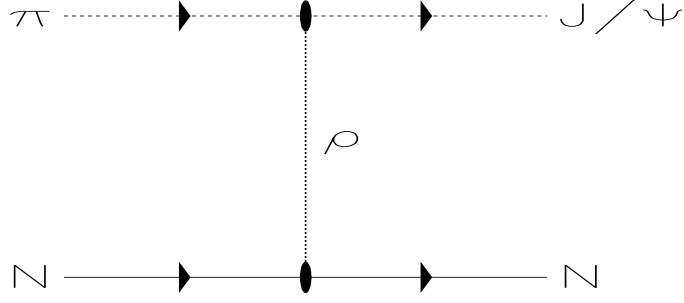


Figure 1: Diagram for  $\pi N \rightarrow J/\Psi N$  reaction due to the  $\rho$ -exchange.

for the  $\pi^- p \rightarrow \phi n$  reaction, in which a box diagram was adopted as the dynamical process that violates the OZI rule. Okubo [7] and Lipkin [8] also noted that the magnitude of the OZI rule violation depends on dynamical mechanisms.

Here we study the role of the dynamical input for the OZI-violating,  $\pi N \rightarrow J/\Psi N$  reaction, and calculate the total cross section using one of the conventional approaches,  $\rho$ -meson exchange. Note that the vertex,  $J/\Psi \leftrightarrow \rho \pi$ , appearing in the present treatment is the OZI-violating process in tree-level.

Effective Lagrangian densities relevant for the process depicted in Fig. 1 may be given by

$$\begin{aligned} \mathcal{L}_{\rho NN} &= -g_{\rho NN} \left( \bar{N} \gamma^\mu \boldsymbol{\tau} N \cdot \boldsymbol{\rho}_\mu \right. \\ &\quad \left. + \frac{\kappa}{2m_N} \bar{N} \sigma^{\mu\nu} \boldsymbol{\tau} N \cdot \partial_\mu \boldsymbol{\rho}_\nu \right), \end{aligned} \quad (1)$$

$$\mathcal{L}_{J\rho\pi} = \frac{g_{J\rho\pi}}{m_J} \epsilon_{\alpha\beta\mu\nu} (\partial^\alpha J^\beta) (\partial^\mu \boldsymbol{\rho}^\nu) \cdot \boldsymbol{\pi}, \quad (2)$$

where we use the value,  $\kappa \equiv f_{\rho NN}/g_{\rho NN} = 6.1$  and  $g_{\rho NN}^2/4\pi = 0.74$ , which were used in Ref. [9].

The  $\pi N \rightarrow J/\Psi N$  amplitude without isospin factor is given by:

$$\begin{aligned} M &= \frac{g_{J\rho\pi} g_{\rho NN}}{m_J^2} \frac{1}{t - m_\rho^2 + i\epsilon} \epsilon_{\alpha\beta\mu\nu} P_J^\alpha \epsilon_J^{*\beta} q^\mu \\ &\times \bar{N}(P'_N) \left( \gamma^\nu - \frac{\kappa}{2m_N} (P'_N + P_N)^\nu \right) N(P_N), \end{aligned} \quad (3)$$

with  $\epsilon_J$  being the  $J/\Psi$  polarization vector.

Then the spin-averaged, squared invariant amplitude has the form:

$$\begin{aligned} |\overline{M}|^2 &= \frac{g_{J\rho\pi}^2 g_{\rho NN}^2}{(t - m_\rho^2)^2} F_{J\rho\pi}^2(t) F_{\rho NN}^2(t) \left\{ -2t q_{ex}^2 \right. \\ &\quad + \left[ 1 - 2\kappa + \kappa^2 \left( 1 - \frac{t}{4m_N^2} \right) \right] [q_{ex}^2(t - 4m_N^2)] \\ &\quad \left. - \frac{t}{4m_J^2} (2s + t - 2m_N^2 - m_J^2 - m_\pi^2)^2 \right\}, \end{aligned} \quad (4)$$

where  $s$  is the squared invariant collision energy and

$$q_{ex}^2 = \frac{(m_J^2 - m_\pi^2 + t)^2 - 4m_J^2 t}{4m_J^2}. \quad (5)$$

The invariant differential cross section is given by

$$\frac{d\sigma}{dt} = \frac{|\overline{M}|^2}{16\pi \lambda(s, m_\pi^2, m_N^2)}, \quad (6)$$

with

$$\lambda(x, y, z) = (x - y - z)^2 - 4yz. \quad (7)$$

The relation between the averaged  $\pi N \rightarrow J/\Psi N$  cross section in isospin space and different isospin channels is given by:

$$\begin{aligned} \bar{\sigma}(\pi N \rightarrow J/\Psi N) &= \frac{1}{2} \sigma(\pi^+ n \rightarrow J/\Psi p) = \frac{1}{2} \sigma(\pi^- p \rightarrow J/\Psi n) \\ &= \sigma(\pi^0 n \rightarrow J/\Psi n) = \sigma(\pi^0 p \rightarrow J/\Psi p). \end{aligned} \quad (8)$$

Note that above formalism can be used also for vector meson production in pseudoscalar + nucleon ( $PN \rightarrow VN$ ) reactions with vector exchange, such as the  $\pi N \rightarrow \omega N$ ,  $\pi N \rightarrow \rho N$ ,  $\pi N \rightarrow \phi N$  and  $KN \rightarrow K^* N$  reactions, by replacing the relevant coupling constants and the form-factors in Eq. (4).

For simplicity we use the same form factor for the vector and tensor couplings in the  $\rho NN$  vertex:

$$F(t) = \frac{\Lambda^2 - m_\rho^2}{\Lambda^2 - t}, \quad (9)$$

with the value for the cut-off parameter,  $\Lambda = 920$  MeV [9], and  $t$  being the 4-momentum transfer from the initial to the final nucleon.

The  $J\rho\pi$  coupling constant,  $g_{J\rho\pi}$ , can be evaluated within the narrow resonance approximation for the  $\rho$ -meson:

$$\Gamma_{J/\Psi \rightarrow \rho\pi} = \frac{g_{J\rho\pi}^2}{32\pi} \frac{\lambda^{3/2}(m_J^2, m_\rho^2, m_\pi^2)}{m_J^5}. \quad (10)$$

Using the measured partial width,  $\Gamma_{J/\Psi \rightarrow \rho+\pi} = 31.12$  MeV [10], we obtain,  $g_{J\rho\pi} = 6.68 \times 10^{-3}$ . Because the  $\rho$ -meson has a width, the  $g_{J\rho\pi}$  coupling constant should be determined properly in a more rigorous treatment [11]:

$$\begin{aligned} \Gamma_{J/\Psi \rightarrow \rho\pi} &= \frac{g_{J\rho\pi}^2}{16\pi^2 m_J^5} \int_{2m_\pi}^{m_J - m_N} d\mu \lambda^{3/2}(m_J^2, \mu^2, m_\pi^2) \\ &\times \frac{\mu^2 \Gamma_{\rho \rightarrow 2\pi}(\mu)}{(\mu^2 - m_\rho^2)^2 + \mu^2 \Gamma_{\rho \rightarrow 2\pi}^2(\mu)}, \end{aligned} \quad (11)$$

where the energy dependence of the  $\rho$ -meson width was taken as

$$\Gamma_{\rho \rightarrow 2\pi}(\mu) = \Gamma_0 \frac{m_\rho}{\mu} \left( \frac{\mu^2 - 4m_\pi^2}{m_\rho^2 - 4m_\pi^2} \right)^{3/2}, \quad (12)$$

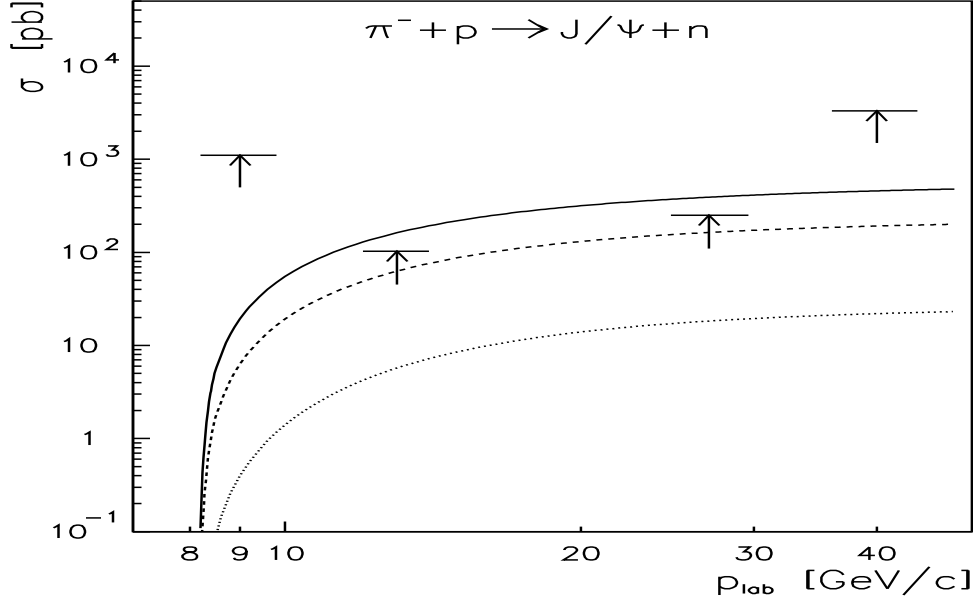


Figure 2: The  $\pi^-p \rightarrow J/\psi n$  total cross section. Arrows indicate the upper limits evaluated from experimental data extracted from  $\pi A$  collisions [3, 15, 16]. Lines show our calculations with the different cut-off parameters:  $\Lambda=1$  GeV (dotted),  $\Lambda=2$  GeV (dashed) and without form factor at the  $J\rho\pi$  vertex (solid).

with  $\Gamma_0=151.2$  MeV. Obviously, in the limit,  $\Gamma_{\rho \rightarrow 2\pi} \rightarrow 0$ , Eq. (11) approaches the narrow resonance approximation of Eq. (10). According to Eq. (11) we get the value for the coupling constant,  $g_{J\rho\pi}=6.78 \times 10^{-3}$ , which is close to the result of the narrow resonance approximation. This is due to the large upper limit of the integral in Eq. (11).

In evaluating the amplitude, one should also account for the nonlocality of the  $J\rho\pi$  vertex, and needs to introduce a relevant form factor. To illustrate the sensitivity of the calculations to the form factor at the  $J\rho\pi$  vertex, we use, in the present study, the same form factor of Eq. (9) and show results for the different values of  $\Lambda$  in Fig. 2. Then, our estimate for the maximal reaction rate may correspond to the results obtained without the form factor at the  $J\rho\pi$  vertex.

Here it should be emphasized that the  $J/\psi$  production has never been observed in exclusive  $\pi N$  reactions. The upper limits have been set at four pion beam momenta and actually were evaluated from  $\pi A$  collisions assuming a linear  $A$ -dependence of the production cross sections [3, 15, 16].

Fig. 2 is the comparison between our results and the upper limits for the  $\pi N \rightarrow J/\psi N$  total cross sections extracted from  $\pi A$  collisions. The dotted, dashed and solid lines show the results with the values for the cut off parameter,  $\Lambda=1$  GeV,  $\Lambda=2$  GeV, and without the form factor at the  $J\rho\pi$  vertex, respectively. The best agreement with the data is for those results obtained without the form factor at the  $J\rho\pi$  vertex. However, even this case the predicted maximum cross section is 140 pb, at pion laboratory momentum 12 GeV/c.

Although the estimate without the form factor at the  $J\rho\pi$  vertex can be regarded as an upper limit in the present treatment of OZI-violating  $\pi N$  collisions, our prediction is still about one order of magnitude smaller than the existing estimates which were based on the other OZI-violating mechanisms, such as duality-violating mechanism [4], a generalized Veneziano model [5], and on the analogy of the  $\pi^- p \rightarrow \phi n$  reaction [6].

However, we should once again recall that there are, as yet, no experimental data for the exclusive  $\pi^- p \rightarrow J/\Psi n$  reaction.

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